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RELATION OF HEAT TREATMENT, MECHANICAL PROPERTIES, AND MICROSTRUCTURE OF 60-40 BRASS

by

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TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS [SUBJECT TO REVISION]

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DISCUSSION OF THIS PAPER IS INVITED. It should preferably be presented in person at the New York Meeting, February, 1924, when an abstract of the paper will be read. If this is impossible, discussion in writing may be sent to the Editor, American Institute of Mining and Metallurgical Engineers, 29 West 39th Street, New York, N. Y., for presentation by the Secretary or other representative of its author. Unless special arrangement is made, the discussion of this paper will close Apr. 1, 1924. Any discsusion offered thereafter should preferably be in the form of a new paper.

Relation of Heat Treatment, Mechanical Properties, and Microstructure of 60–40 Brass

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Dexter N. Shaw, M.Sc., Akron, Ohio

(New York Meeting, February, 1924)

A study of the correlation of the mechanical properties and of the microstructure with the heat treatment of 60–40 brass has been confined, heretofore, to the rolled or extruded material as received from the manufacturer. The results obtained by Babson and Buhler,[1] Bengough and Hudson,[2] Stead and Stedman,[3] and Brayton[4] have been confined to the treatment of the material as received. No attempt was made to get the material into a given condition and then to work from this basis. To start with a given structure would have the decided advantage of making the work independent of the original condition, hence, to make the results reproduceable.

In a previous paper, it was shown, in connection with the study of the transformation that occurs at about 470° C., that if specimens were quenched to produce the beta structure and then reheated, the beta would begin to break down, at approximately 200° C., into a very finely divided alpha. It was predicted that important results might be obtained if test pieces were to be given a similar double heat treatment and then tested for the mechanical properties as well as a study of the microstructure. The material used in the present investigation was a ¾-in. round bar of extruded muntz metal of the following composition: Copper, 61.05 per cent.; zinc (by difference), 38.90 per cent.; lead, 0.05 per cent.; iron, trace; tin, *nil*.

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[1] Babson and Buhler: "Effects that Different Temperatures of Annealing have on the Physical Properties of Brass and the Effects of Different Gases at the Annealing Temperatures on the Microstructure of Brass." M. I. T. Thesis, 1903.

[2] G. D. Bengough and O. F. Hudson: "Heat Treatment of Copper-zinc Alloys." *Jnl.* Soc. of Chem. Ind. (1908) **27,** 43 and 654.

[3] Stead and Stedman: *Op. cit.*

[4] H. M. Brayton: "Heat Treatment of Beta Brasses." *Chem. & Met. Eng.* (1920) **22,** 211.

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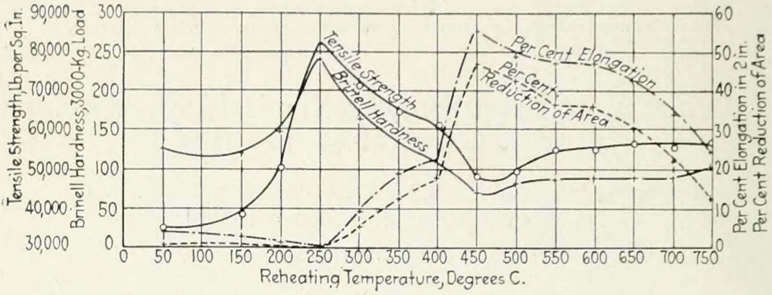

Fig. 1.—Physical properties of test specimens.

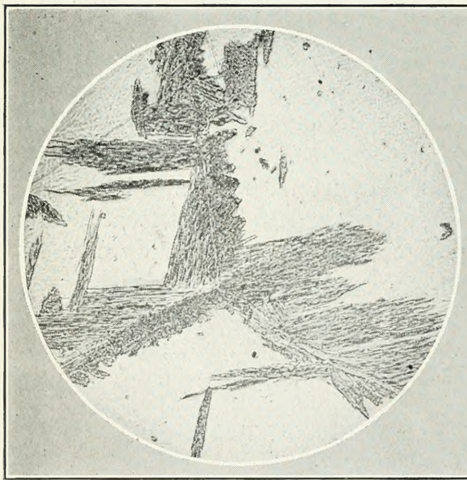

Fig. 2.—Specimen not reheated. × 250.

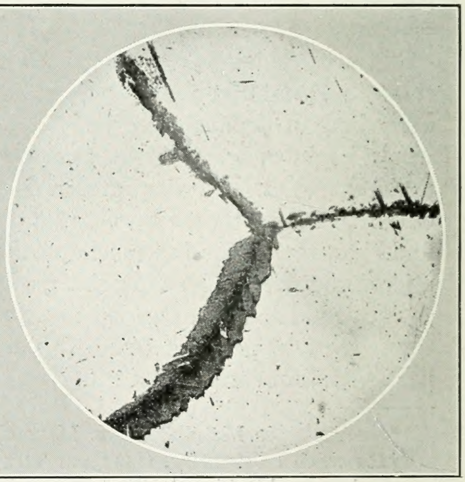

Fig. 3.—Specimen reheated at 150° C. for 2 hr. × 250.

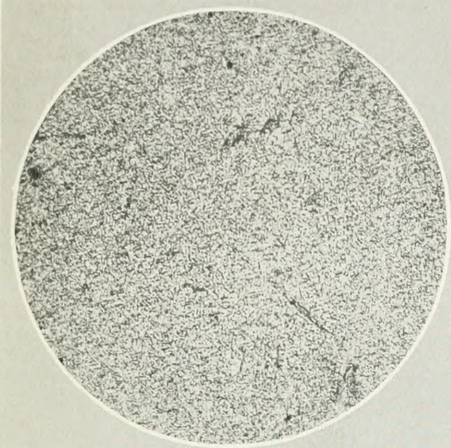

FIG. 4.—SPECIMEN REHEATED AT 200° C. FOR 2 HR. × 250.

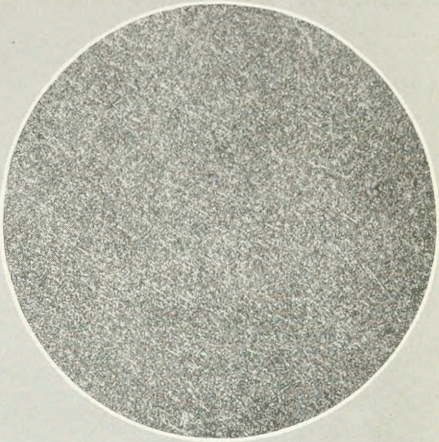

FIG. 5.—SPECIMEN REHEATED AT 250° C. FOR 2 HR. × 250.

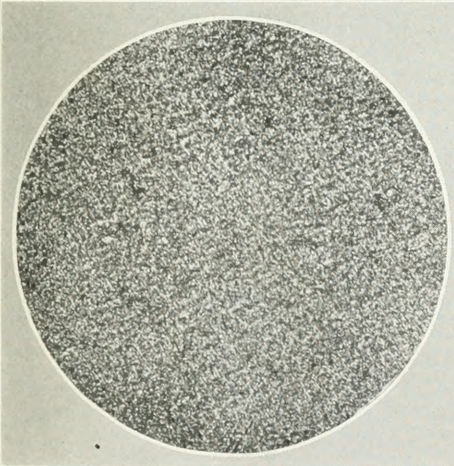

FIG. 6.—SPECIMEN REHEATED AT 300° C. FOR 2 HR. × 250.

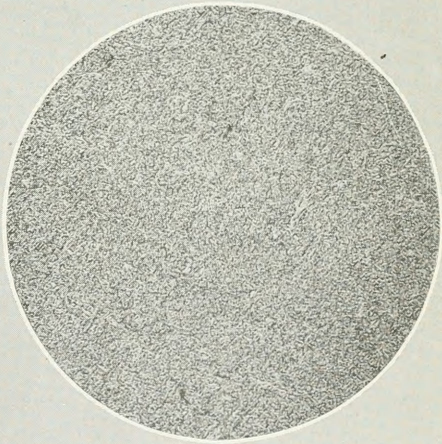

FIG. 7.—SPECIMEN REHEATED AT 350° C. FOR 2 HR. × 250.

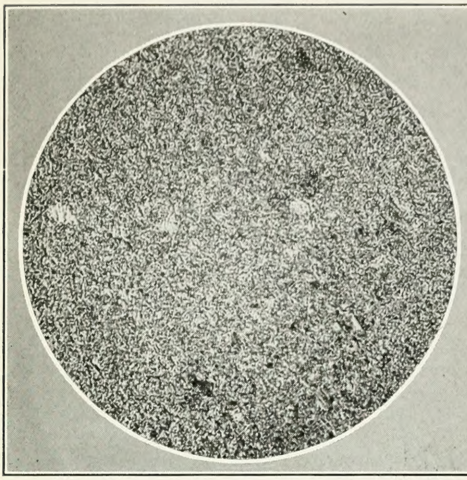

Fig. 8.—Specimen reheated at 400° C. for 2 hr. × 250.

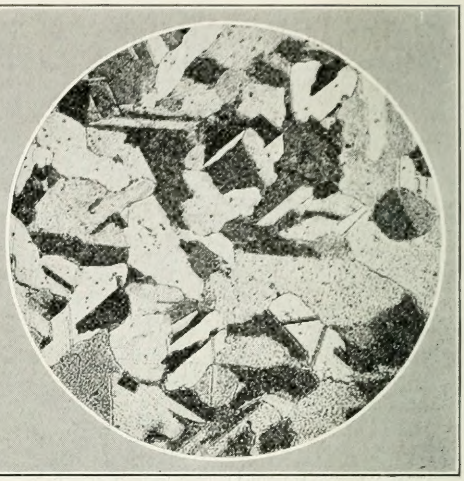

Fig. 9.—Specimen reheated at 450° C. for 2 hr. × 250.

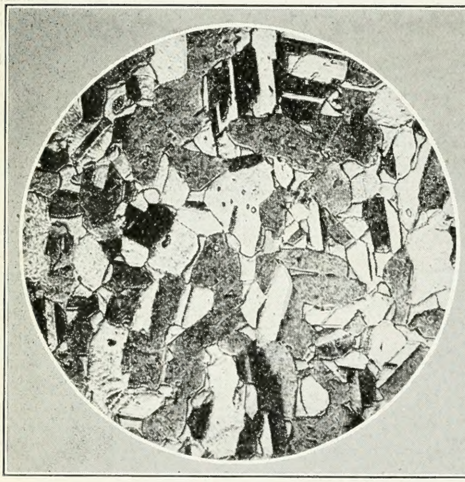

Fig. 10.—Specimen reheated at 500° C. for 2 hr. × 250.

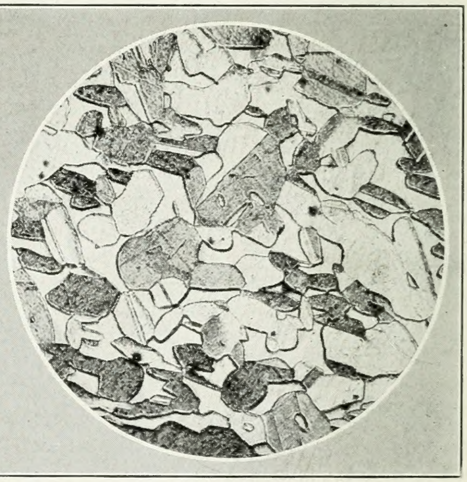

Fig. 11.—Specimen reheated at 550° C. for 2 hr. × 250.

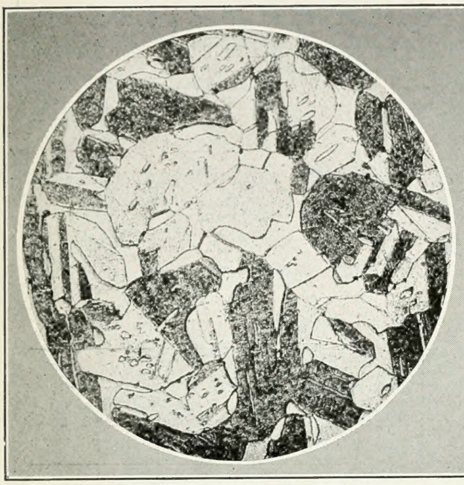

FIG. 12.—SPECIMEN REHEATED AT 600° C. FOR 2 HR. × 250.

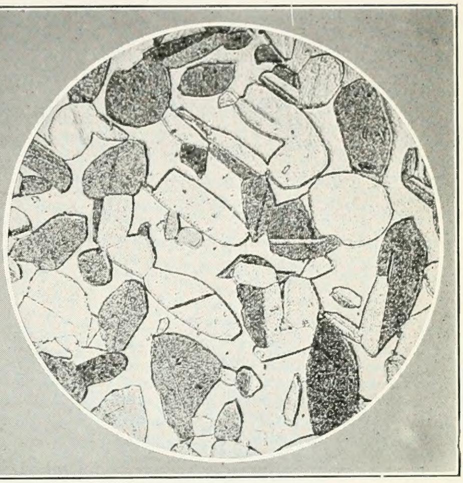

FIG. 13.—SPECIMEN REHEATED AT 650° C. FOR 2 HR. × 250.

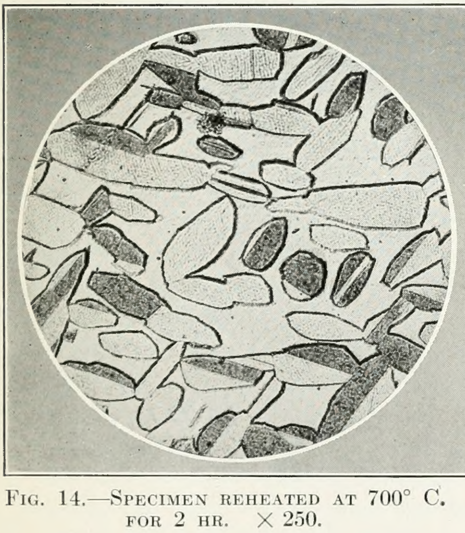

FIG. 14.—SPECIMEN REHEATED AT 700° C. FOR 2 HR. × 250.

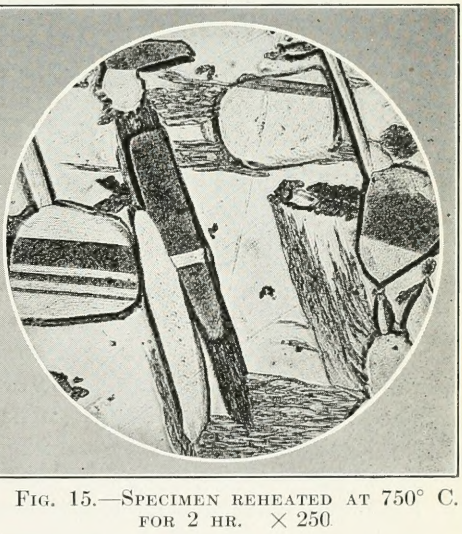

FIG. 15.—SPECIMEN REHEATED AT 750° C. FOR 2 HR. × 250

The test specimens were heated at 825° C. for 2 hr. and then quenched in iced brine, the temperature of which was −8° C. The tensile test pieces were machined to the standard specification of 0.505 in. diameter. These test bars were subsequently reheated for 2 hr. at temperature intervals of 50° C. from 150° to 750° C. and quenched in cold water.

The physical properties are given in Table 1 and the curves in Fig. 1; the structures are shown in Figs. 2–15, inclusive. All specimens were etched with concentrated NH_4OH and H_2O_2 and photographed at 250 diameters. The results may be discussed by dividing the reheating temperatures into three groups; (*a*) 50°–250° C.; (*b*) 250°–450° C.; (*c*) 450°–750° C.

Table 1.—*Physical Properties of Test Specimens*

Reheating Temperature, Degrees C.	Brinell Hardness		Tensile Strength, Lb. per Sq. In.	Per Cent. Elongation in 2 In.	Per Cent. Reduction of Area
	500-Kg. Load	3000-Kg. Load			
Original	119		62,000	35.0	36.7
50	97	126.0	35,000	4.0	0.6
150	100	123.0	38,750	3.0	0.4
200	136	149.0	52,500	1.0	0.2
250		241.0	82,750	0.0	0.0
300		163.0	71,250	9.0	5.4
350	130	131.0	65,000	19.0	12.5
400	119	111.0	61,250	22.0	17.5
450	69	68.0	48,750	55.5	46.7
500	74	82.5	50,000	49.0	42.2
550	74	85.5	55,000	47.0	36.4
600	76	87.1	55,000	47.0	36.0
650	79	88.7	56,750	42.5	30.4
700	85	88.7	55,750	34.0	22.0
750	96	107.0	57,000	24.5	12.6

The physical properties of these reheated specimens, as given in Table 1 and Fig. 1, show a rapid change when heated in the lower range. The tensile strength and the Brinell hardness increase rapidly from the first reheating temperature to 250° C., at which point they reach a maximum. The microstructure changes from crystals of beta, which exist until a temperature of 200° C. is reached, to finely divided alpha; an increase in tensile strength and hardness is to be noted with this change. The structure is finely divided alpha at 250° C., at which temperature the material exhibits remarkable mechanical properties; *i. e.*, maximum hardness and tensile strength with no ductility. Properties analogous to those of martensite in steel are clearly evident. A tensile strength of 82,750 lb. per sq. in. and a Brinell hardness of 241 under a 3000-kg. load are greater than any values previously recorded; these values were checked and are reproduceable. The microstructure showed characteristic grain boundary alpha along the edges of the fracture, thereby indicating an intercrystalline break. All the specimens that were quenched for beta contained a slight fringe of alpha at the grain boundaries.

In the temperature range between 250°–450° C., the tensile strength and the hardness decrease to a minimum while the ductility passes through a maximum. It will be noted from Figs. 5–8 that the finely divided alpha has coarsened with an increase in the reheating temperature. At 450° C. there is a sudden increase in the ductility, as a result of the recrystallization of the alpha into twin crystals. Fig. 9 shows that practically the entire microstructure consists of twinned alpha. The result is a high value for elongation at the expense of hardness. The tensile strength is 48,750 lb. per sq. in.; the hardness is 68 under a 3000-kg. load; the elongation and the reduction of area are 55 and 46.7 per cent., respectively.

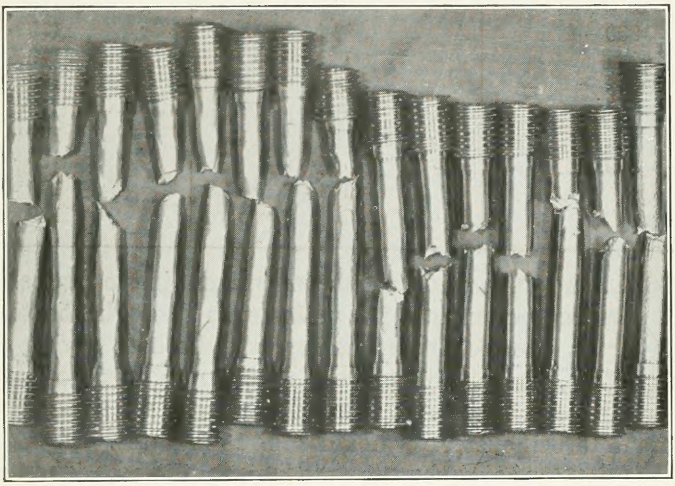

FIG. 16.—TEST BARS AND THEIR FRACTURES.

The third range from 450° to 750° C. shows a gradual increase in tensile strength and in Brinell hardness. Figs. 10–15 show that the proportion of beta has gradually increased. Alpha needles are obtained on quenching from 750° C. Fig. 15 shows beta with unabsorbed alpha twins and needlelike alpha, which is characteristic of the alpha that comes out of the beta on quenching. Fig. 16 shows the fractured test bars.

The effect of the time of heating at the quenching temperature on the Brinell hardness after reheating at 250° C. for 2 hr. was studied. Table 2 indicates the heat treatment and the results obtained:

TABLE 2.—*Heat Treatment and Results Obtained*

Quenching Temperature, Degrees C.	Time at Quenching Temperature, Hours	Brinell Hardness after Reheating at 250° C. (3000 Kg.)
750	¼	149
	½	156
	1	159
	2	166
775	¼	170
	½	179
	1	179
	2	179
800	¼	170
	½	179
	1	179
	2	179
825	¼	170
	½	179
	1	179
	2	179

At 750° C., the alpha reeds, which were present in the original extruded material, persisted throughout the grains even after 2 hr. heating. The needlelike alpha was distributed throughout the beta during the short times of heating but was present only at the grain boundaries when the time of heating was 2 hr. At 775°, 800°, and 825° C., the original alpha reeds were absorbed even after heating for 15 minutes.

The effect of various quenching media was studied. The test pieces were heated at 825° C. for 2 hr., then quenched in different media. They were then reheated at 250° C. for 2 hr., quenched in water, and the physical properties determined. Table 3 gives the results obtained; they show that the only medium that is satisfactory for maximum hardness and tensile strength is iced brine. The beta grains existed in the specimens quenched in water at 25° C. but these were surrounded by large alpha

TABLE 3

Quenching Medium	Tensile Strength, Lb. per Sq. In.	Per Cent. Elongation in 2 In.	Brinell Hardness, 3000 Kg.
Brine at −8°C.	82,750	0.0	241.0
Water at 25°C.	62,000	12.0	179.0
Water at 100°C.	57,500	44.0	74.0
Cold oil	58,200	34.5	85.7

fringes and alpha needles within the grains. The specimens quenched in boiling water and in oil showed no beta as distinct grains.

The effect of the time of reheating at 250° C. was studied by quenching test bars in iced brine after heating for 2 hr. at 825° C. and then reheating for different lengths of time at 250° C. Table 4 gives the results obtained; they show that the breaking down of the beta is very rapid.

TABLE 4

TIME AT 250° C.	HARDNESS (3000 KG.)
15 min	229
30 min	229
1 hr	241
2 hr	241

The effect of the various rates of cooling from the reheating temperature of 250° C. was studied by quenching test bars in iced brine after heating for 2 hr. at 825° C. and then quenching in different media after reheating at 250° C. for 2 hr. The results given, in Table 5, show that the hardness and the tensile strength are practically independent of the rate of cooling from the reheating temperature.

TABLE 5

Quenching Medium	Brinell Hardness, 3000 Kg.	Tensile Strength, Lb. per Sq. In.	Per Cent. Elongation in 2 In.
Cold water	241	82,750	0
Air	229	81,750	0
Cold oil	229		
Iced water	241		

SUMMARY

If brass in the beta condition is used, a gradual increase in hardness and in tensile strength and a gradual decrease in ductility are obtained on reheating the quenched material to 250° C. Between this temperature and 450° C., the reverse is true. From 450° to 750° C., there is a slight increase in hardness and in tensile strength and a decrease in ductility.

The maximum tensile strength of 82,750 lb. per sq. in. and the maximum hardness of 241 with no elongation were obtained at 250° C.; the structure showed very fine alpha and the fracture was intercrystalline.

The maximum elongation of 55.5 per cent. in 2 in. with the lowest Brinell hardness of 68 under a 3000-kg. load and the lowest tensile strength of 48,750 lb. per sq. in. were obtained after reheating to 450° C.; the structure showed only alpha twins and the break was transcrystalline. The Brinell hardness and the tensile strength are proportional.

Satisfactory beta was obtained when the specimen was heated for any length of time greater than ½ hr. at any temperature greater than 775° C. This fact is important, as all of the specimens for which values are given in Table 1 showed a very large grain size. It may, therefore, be possible to get even better values for material treated under such conditions as to obtain a very small grain size. The treatment mentioned above is suggestive.

The specimens must be quenched in iced brine in order to procure maximum hardness and tensile strength on reheating. The change from beta into alpha at 250° C. is rapid. The rate of cooling from 250° C. has no appreciable effect on the physical properties.